

## Conference Paper

# Technogenic Mineral Raw Materials for the Production of Refractories and Ceramics

Vladimir Perepelitsyn<sup>1</sup>, Alexander Yagovtsev<sup>1</sup>, Vitaliy Merzlyakov<sup>2</sup>, Victor Kochetkov<sup>2</sup>, Alexander Ponomarenko<sup>3</sup>, Zinaida Ponomarenko<sup>1</sup>, and Artem Kolobov<sup>1</sup>

<sup>1</sup>JSC "DINUR", Pervouralsk, Sverdlovsk region, Russia

<sup>2</sup>Open Company "Zirkon", Magnitogorsk, Chelyabinsk region, Russia

<sup>3</sup>Department of materials sciences in construction of the Institute of new materials and technologies, Ural Federal University, Yekaterinburg, Russia

## Abstract

Chemical–mineral and material–genetic classifications of technogenic mineral raw materials including up to 36 polyphase groups of materials that form the basis of secondary resources suitable for the production of refractories and ceramics after additional processing are proposed. It is shown that technogenic materials of the Urals are cheap multifunctional raw materials and can be used in the production of magnesia-silicate ceramics, carbon– and zirconium–containing high-alumina refractories and cements.

**Keywords:** classification, secondary mineral resources, composition, recycling, refractories, ceramics.

Corresponding Author:

Vladimir Perepelitsyn

pva-vostio@bk.ru

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## 1. The Urgency of the Problem of Technogenic Wastes

The amount of industrial waste has been growing exponentially over the past 100 years. Over 25 billion tons of only solid technological wastes are produced in the world annually. The third part (>7 billion tons) of this amount are produced in Russia. In the Russian Federation at the beginning of 2013 more than 90 billion tons of production wastes of consumption were accumulated. The area occupied by organized waste disposal zones is more than 400 thousand hectares. Geoecological problems of technogenic wastes are connected not only with environmental protection but directly also with the economic development of the regions. Waste generation is also an indicator of the unsustainable use of natural resources while many of them are on the verge of exhaustion. Therefore the rehabilitation of industrial waste is an urgent natural resource, environmental, geoecological and economic task.

On the one hand waste recycling is a instrument of increasing production efficiency and saving resources and on the other is a natural mandatory condition for restoring of equilibrium in the biosphere as it reduces the burden on ecosystems and increases their

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sustainability. In Russia there are various Federal and regional programs whose primary purpose is providing basic conditions for environmentally safe sustainable development of country through the creation of normative, scientific and technological base, i.e. the unified state policy in the sphere of waste management at all levels, ensuring of stabilization and further reduction and elimination of environmental pollution as well as access to savings of natural resources due to maximum involving of secondary waste in the economic turnover. One of the promising directions of the innovation process is the complete recycling of industrial waste within the framework of regional economic complexes. It includes the extraction of valuable and deficit materials (pure oxides, noble, non-ferrous, rare, radioactive and other elements) from industrial waste and the creation of structural and functional materials with high performance properties instead of natural traditional materials and metals. The implementation of this strategy will significantly reduce the consumption of primary natural resources by more than 25 % as well as to solve the issues of raw material security of the country.

**Chemical–mineral classification of technogenic refractory and ceramic raw materials.** The following classification of technogenic raw materials by chemical and mineral composition are offered.

1. Silica ( $\text{SiO}_2 \geq 90$  mass. %).
2. Aluminosilicate ( $\text{Al}_2\text{O}_3$ – $\text{SiO}_2$  system, each oxide 10–90 mass. %).
3. Corundum (alumina,  $\text{Al}_2\text{O}_3 > 90$  mass. %).
4. Magnesite ( $\text{MgO} \geq 90$  mass. %).
5. Magnesite–spinel (system  $\text{MgO}$ – $\text{R}_2\text{O}_3$ , where  $\text{R}_2\text{O}_3$  –  $\text{Al}_2\text{O}_3$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{Ti}_2\text{O}_3$ ,  $\text{Mn}_2\text{O}_3$ ,  $\text{MgO} > \sum \text{R}_2\text{O}_3$ ).
6. Magnesite–silicate (system  $\text{MgO}$ – $\text{SiO}_2$ ,  $\text{MgO} > 50$  mass. %).
7. Magnesite–lime ( $\text{MgO}$ – $\text{CaO}$  system at the ratio of components (70:30)÷(30:70).
8. Lime–silicate system ( $\text{CaO}$ – $\text{SiO}_2$ , 65–75 mass. %  $\text{CaO}$ , 25–35 mass. %  $\text{SiO}_2$ ).
9. Lime–aluminate (the system  $\text{CaO}$ – $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$  8–30,  $\text{Al}_2\text{O}_3$  70–92 mass. %).
10. Lime ( $\text{CaO} \geq 90$  mass. %).
11. Zirconium–containing (the system  $\text{ZrO}_2$ – $\text{Al}_2\text{O}_3$ – $\text{Cr}_2\text{O}_3$ – $\text{CaO}$ – $\text{MgO}$ – $\text{Y}_2\text{O}_3$ – $\text{SiO}_2$ – $\text{C}$ ,  $\text{ZrO}_2 \geq 5$  mass. %).
12. Silicon carbide containing (system  $\text{SiC}$ – $\text{Al}_2\text{O}_3$ – $\text{SiO}_2$ – $\text{C}$ ,  $\text{SiC} \geq 10$  mass. %).
13. Carbonaceous system ( $\text{RO}$ – $\text{R}_2\text{O}_3$ – $\text{RO}_2$ – $\text{C}$ , where  $\text{RO}$  –  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{VAO}$ ;  $\text{R}_2\text{O}_3$  –  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{Ce}_2\text{O}_3$ ;  $\text{RO}_2$  –  $\text{ZrO}_2$ ,  $\text{SiO}_2$ ,  $\text{TiO}_2$ ).
14. Nitrogen–containing (system  $\text{Si}$ – $\text{Al}$ – $\text{Ti}$ – $\text{O}_2$ – $\text{N}_2$ ,  $\text{N}_2 \geq 5$  mass. %).
15. Special (borides, nitrides, silicides, REE compounds of various chemical classes, oxycarbides, oxynitrides, etc.).

The proposed variant of chemical–mineral classification includes 15 potential groups of secondary resources of inorganic composition which can be used to some extent in the production of refractories and ceramics as the main component of the charge or functional additives. Certainly this classification cannot be qualified as full one of all other chemical classes which are known and currently used in the manufacture of new refractory compounds (partially attributed to the 15th group): chromite ( $\text{LaCrO}_3$ ), complex oxides ( $\text{Y}_3\text{Al}_5\text{O}_{12}$  – yttrium – aluminum garnet), phosphates ( $\text{AlPO}_4$ , etc.), titanate ( $\text{CaTiO}_3$ ,  $\text{SrTiO}_3$ , etc.) as well as a number of metals with high melting point (W, Mo, CR, etc.), there are more than 150 substances. Each group of secondary raw minerals in turn usually contains several technogenic materials each of which has not only sufficient fire resistance but also a set of other valuable properties. According to the modern multifunctional concept any primary (natural and synthetic) or secondary (technogenic) raw material has a set of physical and chemical properties that allow to use it as a raw material in two or more industries.

For example corundum and silicon carbide are not only wear–resistant refractory materials but also high–quality abrasives and ceramics and silicon carbide is also an excellent high–temperature electric heater. Therefore each mineral (inorganic compound) and especially polyphase materials including technogenic is a multifunctional raw material.

**Technogenic raw materials of the Urals for the refractories and ceramics production.** After the collapse of the USSR in the refractory and ceramic industry of Russia the problems of providing high–quality magnesium, aluminosilicate, high–alumina, zirconium raw materials as well as graphite and chromite sharply aggravated. Many years of experience of the Eastern Institute of refractories (Ekaterinburg) showed that one of the ways out of the raw material crisis is the use of man–made mineral resources.

Over the past 90 years more than 20 billion tons of technogenic formations have been accumulated in the Ural region; among of which more than 70 % can be recycled as secondary mineral raw materials. The main suppliers of man–made raw materials are mining and metallurgical industries as well as heat and power engineering using solid fuels. Among the many varieties of secondary mineral raw materials besides a refractory scrap of waste linings of thermal aggregates there are a variety of inorganic materials and substances that can be used in the refractory industry. Due to strict fire resistance requirements (at least 1580 °C) only about 1 % of the total secondary mineral resources can be used as raw materials for the refractories production. Approximately 5 % of technogenic wastes are suitable for coarse and fine ceramics production.

Nowadays domestic and foreign industries use for this purpose more than 150 different primary raw materials including more than 100 substances of inorganic composition.

The material composition of raw materials is represented by compounds of various chemical classes: oxides, silicates, carbides, nitrides, elements, phosphates, hydroxides, to a lesser extent borates, sulfates and others. Depending on the origin (genesis) inorganic varieties of raw materials can be combined into three large groups: natural, synthetic and technogenic.

According to Russian Standard no. 28874 refractories are classified in to 17 types by the chemical–mineral composition: siliceous, aluminosilicate, alumina, alumina–lime, magnesia, magnesia–lime, lime, magnesia–spinline, magnesia–silica, chromium, zirconite, oxide, carbon, carbide–silica, oxygen–free, sialons and special of complex composition.

Taking into account this standard classification and the availability of accessible raw materials a material–genetic classification of the main (mass) varieties of mineral raw materials used for the manufacture of refractories have been developed (see Table 1). Among the many varieties of natural and synthetic refractory raw materials 12 chemical classes which include 36 groups of natural minerals and artificial compounds are formed. Natural, synthetic and technogenic mineral (inorganic) raw material is represented by silica, silica–alumina, corundum, magnesia, magnesia–spinline, magnesia–silica, magnesia–lime, carbon–, zirconium–, carbide–silica–containing, alumina–lime and oxide (special) materials.

The general characteristics of the main types of technogenic refractory mineral raw materials are given in Table 2.

The most high–refractory industrial materials are represented mainly by substandard dump magnesite, magnesite waste of talc enrichment, fly dust of burning and melting furnaces (caustic magnesite), the disintegration waste and the cortical area of melted magnesia blocks and magnesia products of chemical industry (chlorides, sulfates and carbonates of magnesium).

Substandard chrome ores of Saranovskoye deposit, nonmetallic products of their enrichment, serpentine tailings of talc and asbestos enrichment, cyclone dust of furnaces for dunite production, forsterite–spindle ferroalloy slags and other materials include magnesium–silicate wastes. The total annual growth of such waste is 20 million tons, the reserves in the dumps are more than 4.5 billion tons including wastes from the extraction and enrichment of asbestos is about 4.0 billion tons.

Technogenic aluminosilicate raw materials are represented by a large group of kaolin and alumina–containing materials, namely high–alumina waste of chemical industry catalysts, overburden and coal enrichment waste (clay + coal), fly ash of thermal power plants and rotary kilns for alumina and fireclay burning, sludge waste of electrocorundum of abrasive production, high–alumina ferroalloy alumothermic slags, aluminum–containing

TABLE 1: Classification of the main types of refractory raw materials (authors' work).

Refractory type, system (composition, mass. %)	Genetic varieties of raw materials		
	Natural	Synthesized	Technogenic
Siliceous $\text{SiO}_2$	Quartzite, marshalite, quartz, opal, diatomite, quartz sand	Silica glass $\text{SiO}_2$ (lechatelierite), glass fiber $\text{SiO}_2$	Microsilica, slurry quartzite
Aluminosilicate $\text{Al}_2\text{O}_3\text{--SiO}_2$ and corundum $\text{Al}_2\text{O}_3$ $\sum(\text{Al}_2\text{O}_3+\text{SiO}_2) > 70$	Refractory clay, kaolin, topaz, kyanite, andalusite, sillimanite, bauxite, iron-poor, quartz sand	Tubular corundum, melted corundum: white, normal, doped. Melted mullite. Aluminosilicate fiber	Slurry corundum, pyrophyllite, alumina fly dust, catalysts wastes of organic synthesis, secondary refractories, alumino-thermal slags, aluminosilicate ash
Magnesian $\text{MgO} \geq 85$	Magnesite, brucite, hydromagnesite, huntite, bishofite	Periclase: sintered, melted, magnesium	Fly dust from kilns (caustic magnesia). Substandard brucite and magnesite
Magnesia-spinel $\text{MgO--Cr}_2\text{O}_3$ , $\text{MgO--Al}_2\text{O}_3$ , $\text{MgO--FeO--Al}_2\text{O}_3$	Magnesite, chromite. Chromespinelides: magnochromite, aluminochromite, ferro chromicotite, chromite	Periclase-chromite: sintered, melted. Spinel: sintered, melted. Hercinitis. Melted chromium alumina spinelid	Chromia-alumina catalysts of petrochemical industry, carbon ferrochromium slags (silicate-spinel)
Magnesia-silica $\text{MgO--SiO}_2$ $\sum(\text{MgO}+\text{SiO}_2) \geq 60$	Dunite, olivinite, serpentine, talc, talcum magnesite	Dolomite: sintered, melted. Dunite: sintered, melted. Forsterite: sintered, melted	Slags of ferrochrome, wastes of talc flotation and chrome ore enrichment
Magnesia-lime $\text{MgO--CaO}$ $\text{MgO} \geq \text{CaO}$	Dolomite, dolomitized magnesite, limestone, chalk, etc.	Dolomite: sintered, melted	Kiln fly dust, carbide sludge $\text{Ca}[\text{OH}]_2$
Carbonaceous $\text{C}+\text{RO}+\text{RO}_2+\text{RO}_2\text{R}_2\text{O}_3$ $\text{C}=4-40$	Graphite, shungite, anthracite, quartz	Artificial graphites, technical carbon. Mixes with $\text{MgO}$ , $\text{Al}_2\text{O}_3$ , spinel $\text{ZrO}_2$ , $\text{SiO}_2$ etc.	Graphite spell, oven electrodes, secondary refractories, wastes of electrodes graphitizing
Zirconium-containing $\text{ZrO}_2\text{--SiO}_2$	Baddeleyite, zircon	Baddeleyite: sintered, melted, bakor	Secondary refractories
Silicon-carbide-containing $\text{SiC}$	Quartz, shungite, graphite, coal	Silicon carbide: green, black, silicified graphite	Wastes of electrodes graphitizing ( $\text{SiC}+\text{SiO}_2$ )
Alumina-lime, $\text{CaO}=8-30$ , $\text{Al}_2\text{O}_3\text{--CaO}$	Limestone, chalk, bauxite	Bonit, high alumina cement, alumina cement	Alumothermic toxins
Oxide special $\text{RO}, \text{R}_2\text{O}_3, \text{RO}_2$	Beryl, cassiterite	$\text{BeO}$ , $\text{Cr}_2\text{O}_3$ , $\text{Y}_2\text{O}_3$ , $\text{SnO}_2$	Secondary refractories and ceramics

etching solutions of nonferrous metallurgy and synthesis of organic compounds (phosphates, alcoholates of aluminum, etc.). The total annual growth of these materials in the region is 500-600 million tons.

Substandard and slurry quartzite, silica fume dust from production of crystalline silicon and silicon ferro-alloys (up to 98 %  $\text{SiO}_2$ ) and very large-scale quartzite (substandard) and quartz waste of refractory and mining industries and other materials are included in the group of technogenic high-silica materials.

The most common are refractory calcium-containing materials which are dolomite and limestone piles, self-disintegrated ferroalloy refining slags, bauxite (red) and nepheline sludges, lime-aluminate (aluminate-thermic) ferroalloy slags, fly ashes of furnaces for dolomite and lime burning. Graphite spel of blast furnace production, graphite and silicon carbide wastes of metallurgical, chemical and ceramic industries are of interest from the group of carbon-containing waste for the refractory industry. The most valuable among them are used oxide-lining.

In addition to the traditional use of non-metallic components the use of refractory technogenic materials for the production of refractories, ceramics, cements and other more high-tech and expensive products is technically and economically more effective as cheap raw materials for the construction industry. It can quickly get the economic effect and return on investment especially during the recycling of technogenic wastes in the refractory and ceramic industry.

TABLE 2: The main technogenic resources of refractory and ceramic raw materials (authors' work).

Types and sources of secondary raw materials	Material composition (base)	Mineral (phase) composition	Stocks (order) [tons]	Possible use
<b>Magnesian</b>				
Dumping brucite	Brucite, magnesite	$\text{MgO}(\text{OH})_2$ , $\text{MgCO}_3$ , $\text{CaMg}(\text{CO}_3)_2$	$n \cdot 10^3$	Periclase refractories
Substandard magnesite	Magnesite, dolomite	$\text{MgCO}_3$ , $\text{CaMg}(\text{CO}_3)_2$	$n \cdot 10^5$	–
Dolomite dumps	Dolomite, calcite, clay	$\text{CaMg}(\text{CO}_3)_2$ , $\text{CaCO}_3$	$n \cdot 10^7$	–
Talc-magnesite waste	Magnesite, hematite, chlorite	$\text{MgCO}_3$ , $\text{Fe}_2\text{O}_3$	$n \cdot 10^4$	Filling powders
Magnesian fly dust	Periclase, magnesite	$\text{MgO}$ , $\text{MgCO}_3$		Magnesia refractories and cements
Chloride and carbonate magnesia wastes	Bischofite, carnallite, hydromagnetic	$\text{MgCl} \cdot 6\text{H}_2\text{O}$ , $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$	$n \cdot 10^4$	Periclase refractories and concretes
Magnesian secondary refractories	Periclase, mpurities	$\text{MgO}$ , $\text{CaMgSiO}_4$ , $\text{Ca}_2\text{SiO}_4$ , $\text{MgFe}_2\text{O}_4$		Basic refractories
<b>Aluminosilicate and alumina-containing</b>				
Wastes of alumina catalysts for organic synthesis	Alumina, chromium oxide, silica	$\gamma\text{-Al}_2\text{O}_3$ , $\text{SiO}_2$ , $\text{Cr}_2\text{O}_3$	$n \cdot 10^5$	High alumina refractories

Types and sources of secondary raw materials	Material composition (base)	Mineral (phase) composition	Stocks (order) [tons]	Possible use
Alumothermic slags	Calcium aluminates, spinel, corundum	$\text{CaO} \cdot \text{Al}_2\text{O}_3$ , $\text{CaO} \cdot 2\text{Al}_2\text{O}_3$ , $\text{CaO} \cdot 6\text{Al}_2\text{O}_3$ , $\text{MgAl}_2\text{O}_4$	$n \cdot 10^3$	High alumina cement
Sludge wastes of electrocorundum	Corundum, iron	$\alpha\text{-Al}_2\text{O}_3$ , $\alpha\text{-(Al,Cr)}_2\text{O}_3$	$n \cdot 10^3$	High alumina refractories
Aluminosilicate ashes of heat power engineering	Aluminosilicate glass	$\text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$ , $\text{Fe}_2\text{O}_3$ , $\text{Fe}_3\text{O}_4$	$n \cdot 10^7$	Chamotte lightweight refractories
Pyrophyllite-containing rocks	Pyrophyllite, quartz	$\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$ , $\text{SiO}_2$ , $\text{FeS}_2$	$n \cdot 10^3$	Chamotte
Aluminosilicate secondary refractories	Mullite, glass	—	—	—
Dust from fireclay kilns and rotary kilns for alumina production	Kaolinite, metakaolinite, alumina	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ , $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ , $\text{Al}_2\text{O}_3$	$n \cdot 10^5$	—
<b>Magnesia-silicate</b>				
Tailings of chrome ore enrichment	Serpentine, brucite	$3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ , $\text{Mg(OH)}_2$	$n \cdot 10^7$	Forsterite refractories and steatite ceramics
Tailings of asbestos enrichment	—	$3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ , $\text{Mg(OH)}_2$ (Mg,Fe) $(\text{Cr,Fe,Al})_2\text{O}_4$	$n \cdot 10^9$	Steatite ceramics
Substandard chrome ore	Chromite, serpentine	$3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$	$n \cdot 10^6$	Chrome–forsterite refractories
Tailings of talc enrichment	Talc, magnesite, chloride	$3\text{MgO} \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O} \cdot \text{M}$	$n \cdot 10^4$	Forsterite refractories
The olivine concentrates from enrichment	Olivenite, calcite	$(\text{Mg,Fe})_2[\text{SiO}_4]$ , $\text{CaCO}_3$	$n \cdot 10^4$	—
Slag of carbon ferrochrome	Forsterite, spinel	$\text{Mg}_2[\text{SiO}_4]$ , $\text{Mg(Al,Cr)}_2\text{O}_4$	$n \cdot 10^5$	Forsterite–spinel refractories
<b>Zirconium-containing</b>				
Bakor products from linings of glass kilns Products scrap of production in continuous casting machine Scrap of corundum–mullite–zirconium products	Baddeleyite Corundum Glass Baddeleyite Corundum mullite	$\text{ZrO}_2(\text{mon})$ $\text{Al}_2\text{O}_3$ $\text{ZrO}_2(\text{mon})$ $\text{ZrO}_2(\text{cub})$	$n \cdot 10^5$	Bakor Spinel High alumina refractories and special ceramics
<b>Siliceous</b>				
Dusts of silicon alloys	Amorphous silica	$\text{SiO}_2$	$n \cdot 10^5$	Siliceous masses
Quartz wastes of enrichment of kaolin, clay ores etc.	Quartz, clay	$\text{SiO}_2$ , $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$	$n \cdot 10^4$	Monolithic lining

Types and sources of secondary raw materials	Material composition (base)	Mineral (phase) composition	Stocks (order) [tons]	Possible use
Pyrophyllite wastes	Quartz, pyrophyllite, pyrite	$\text{SiO}_2$ , $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$ , $\text{FeS}_2$	$n \cdot 10^6$	–
Quartz–mica wastes	Quartz, muscovite	$\text{SiO}_2$ , $\text{K}_2(\text{OH})_2$ ( $\text{AlSi}_3\text{O}_{10}$ )	$n \cdot 10^6$	–
Wastes of molding earths (sands)	Quartz, cristobalite, glass, iron	$\text{SiO}_2$ , Fe, $\text{Fe}_3\text{O}_4$	$n \cdot 10^4$	–
<b>Lime-containing</b>				
Fly dust from kilns for lime and dolomite firing	Lime, periclase, dolomite	$\text{CaO}$ , $\text{MgO}$ , $\text{CaMg}(\text{CO}_3)_2$	$n \cdot 10^4$	Lime–periclase refractories
Dolomite dumps	Dolomite, limestone	$\text{CaMg}(\text{CO}_3)_2$ , $\text{CaCO}_3$	$n \cdot 10^7$	–
Самораспадающиеся ферросплавные шлаки	Calcium orthosilicates	$\gamma\text{-Ca}_2(\text{SiO}_4)$ , $\text{Mg}(\text{Al,Cr})_2\text{O}_4$	$n \cdot 10^5$	Lime–silicate refractories
Steel–rifining slags	The aluminates of calcium	$\text{Al}_2\text{O}_3 \cdot \text{CaO}$ , $12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$	$n \cdot 10^4$	–
Electro-thermophosphoric slags	Wollastonite, anortite	$\text{CaSiO}_3$ , $\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$	$n \cdot 10^4$	Slag–forming mixes
Bauxite and nepheline slurries	Calcium silicates, calcite, hematite, aluminates	$\text{Ca}_2\text{SiO}_4$ , $\text{CaCO}_3$ , $\text{Fe}_2\text{O}_3$ , $\text{NaAlO}_2$	$n \cdot 10^6$	–
Lime and dolomite slurries	Slaked lime, brucite	$\text{Ca}(\text{OH})_2$ , $\text{MgO}$ , $\text{Mg}(\text{OH})_2$	$n \cdot 10^5$	Lime–periclase refractories
<b>Carbonaceous</b>				
Scrap of oxide–carbon refractories	Graphite, periclase, corundum, spinel	C, Mg, $\text{Al}_2\text{O}_3$ , $\text{MgAl}_2\text{O}_4$	$n \cdot 10^3$	Oxide–carbon refractories
Graphite spell	Graphite, iron, slag	C, $\alpha\text{-Fe}$	$n \cdot 10^5$	Carbonaceous refractory
Wastes of electrodes graphitizing	Graphite, carborundum	C, SiC, $\text{SiO}_2$	$n \cdot 10^4$	Carbide–silicon refractories
Slurry carborundum	Silicon carbide, iron	SiC, $\alpha\text{-Fe}$	$n \cdot 10^3$	–
Silicon carbide kapseli	Silicon carbide, glass	SiC, $\text{SiO}_2$	$n \cdot 10^2$	Carbonaceous refractory
Electrode cinders of electrolyzers	Graphite, carbon	$\text{C}_{cr}$ , $\text{C}_{amor}$	$n \cdot 10^2$	–

## 2. Conclusion

A variant of chemical–mineral classification of technogenic mineral raw materials including 15 groups of secondary mineral resources suitable for the production of refractories



and ceramics after additional processing is offered. The secondary mineral resources primarily of the Urals region are considered. The estimated total reserves of these raw materials in the Ural region exceed 140 million tons.

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